GaAs Photodetector for X-ray Imaging

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ABSTRACT

We describe briefly a cheap and non polluting technique to grow epitaxial GaAs layers, several hundred microns thick, in a matter of hour. Detectors consisting of a $p^+/i/n^+$ structure have been realised with these layers and we present their characteristics obtained from current-voltage, capacitance-voltage measurements as well as their response versus the energy and flux of X-rays.

INTRODUCTION

In the 1960s it has been suggested that GaAs could be a good alternative material for high energy photon detection [1]. Since then, various experiments have demonstrated that GaAs detectors exhibit indeed high performances in terms of charge collection efficiency and energy resolution [2-7]. These detectors were the first to demonstrate high resolution at room temperature (for a review see ref.8). However, no GaAs detector has appeared on the market although the development of a microelectronic technology for this material could have allowed an easy realization of many kinds of structures, ohmic contacts, barriers, junctions and electronics integration. The reason is the following: large thicknesses are required to detect efficiently X and γ photons, thicknesses which are only available from bulk grown materials. Unfortunately, bulk GaAs materials contain a large concentration of defects which, in addition, are not uniformly distributed (for a review see ref.9). For these reasons it has been accepted that these materials are not suitable in practice to develop detectors, in particular imaging detectors.

Only good quality materials, i.e. obtained by epitaxy, qualify for detection. All conventional epitaxial growth techniques seem to satisfy this requirement: the data claimed in ref.3 to be due to the very high purity associated with a specific epitaxial growth, are in fact similar to those reported 28 years earlier [4-7], which were obtained with other types of epitaxial growth techniques. But epitaxial layers of large enough thickness do not exist: the data reported in references 2 to 7 have been acquired on unique layers. Indeed, epitaxial growth techniques are slow: they allow to obtain a few microns thick layer in a matter of hour. Hence, to grow several hundred microns thick layers, the ones which would allow efficient absorption for X-ray, days of continuous growth are necessary, which is industrially impracticable.

However the situation could be different now that we have demonstrated that 100 to 600 μm thick epitaxial layers can be obtained in few hours using an economic and non polluting technique [10,11]. Since it has been previously demonstrated that high performances detectors can be obtained with epitaxial layers, we examine here if the new layers we produce, in large quantity, at the desired thickness, and having electronic properties similar to that of the previously used layers [12], could make detectors with similar performances.

For this we made p/i/n detectors and we investigated their response in conditions of X-ray medical examination. Here, we focus on the linearity of this response and we evaluate the efficiency of collection.

EXPERIMENTAL

We have grown non intentionally doped 200 to 300 μm thick layers on n^+, Czochralski (Cz) grown, GaAs substrates. Briefly the technique, which is fully described in ref.10, consists in the decomposition of a source material, here GaAs originating from a semi-insulating (S.I.), Cz grown wafer, by H_2O in an H_2 atmosphere at a temperature of the order of 800 °C. The volatile species, As_2 and Ga_2O, which are formed are transported by their partial pressure gradients to a substrate located at a short distance (typically from 1 to 2 mm) from the source. The reverse reaction takes place on the substrate because its temperature is lower than that of the source, and epitaxial growth occurs. Because the rate of material deposition is only limited by the rate of the chemical reactions taking place, the growth rate can be adjusted to very high velocities (up to 10 $\mu m.min^{-1}$). By the choice of the temperature, it is therefore possible to grow a several hundred μm thick epilayer in a matter of hours. The reactor being very simple and requesting only a small amount of pure H_2 (the volume of the reactor), this technique is cheap and non polluting.

As described elsewhere, the residual doping depends on the purity of the source material and on the ability of the reaction to induce impurity transport (as described in ref.13, only the impurities producing volatile species with the reactant, here H_2O, are transported). When using Cz, S.I. wafers as sources, the doping level achieved is in the range 10^{13} to 10^{15} cm^{-3} and can be n or p type depending on the origin of the source. In order to reduce this doping (to increase the width of space charge region for a given bias of the detector), two ways are attempted: electron irradiation which introduces defects compensating the dopants [14] and selection of the source material (which should contain only impurity which are not transported, for instance Si for the n type impurity).

We have performed ion implantation to make a p^+ layer on the surface of a 170 μm thickness layer grown on an n^+ substrate and obtain $p^+/i/n^+$ structures in which the i region is the grown layer. After deposition of ohmic contacts, on both sides, these structures were characterized by current-voltage (I-V) and capacitance-voltage (C-V) measurements, demonstrating that the current is of the order of 3 $nA.mm^{-2}$ for a reverse bias of 10 V (see figure 1) and that the residual doping is in the range of 10^{13} to 10^{14} cm^{-3}. For instance figure 2 shows that the doping is 5×10^{13} cm^{-3}; such doping level corresponds to a space charge region of 18 μm for the reverse bias of 10 V.
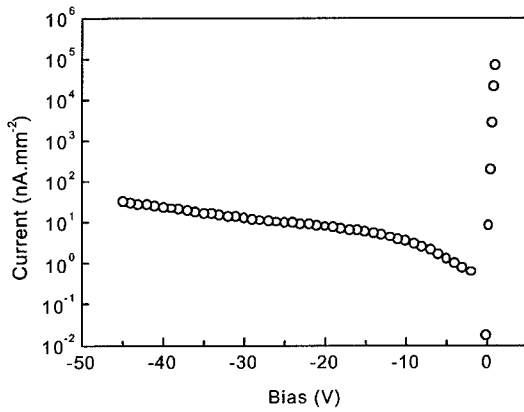
Figure 1. Current-Voltage characteristics obtained with a 27.5 mm^2 detector.
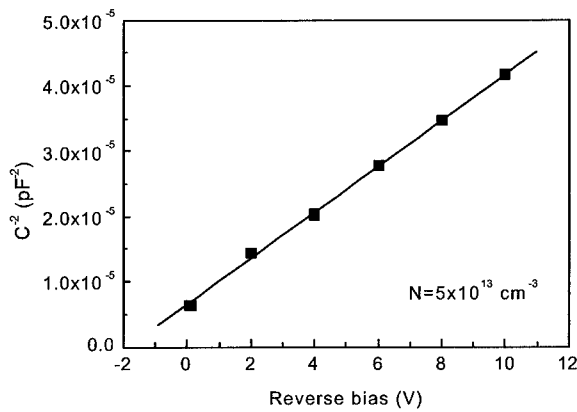

Figure 2. Typical Capacitance-Voltage characteristics obtained with a 27.5 mm^2 detector.

The study of the response with the fluence of X-ray has been performed using a machine whose energy is not stabilized so that the flux is modulated at 50 Hz. The current I delivered can be adjusted from 5 to 25 mA. The detector is polarized under 10 V across a 1 MΩ resistance. We monitored the modulated signal, i.e. the current flowing through this resistance, via an oscilloscope.

RESULTS AND DISCUSSION

The dependence of the signals versus the current I, monitored for accelerating voltages of 50 kV and 30 kV, at a distance of 32 cm from the X-ray source, with a detector of area 27.5 mm^2 is given in figure 3. The dependence demonstrates the linearity of the detector in the photon flux explored, up to at least 1.2×10^8 photons mm^{-2}.s^{-1} (The number of photons is calculated with a program based on a code described in ref. 15).
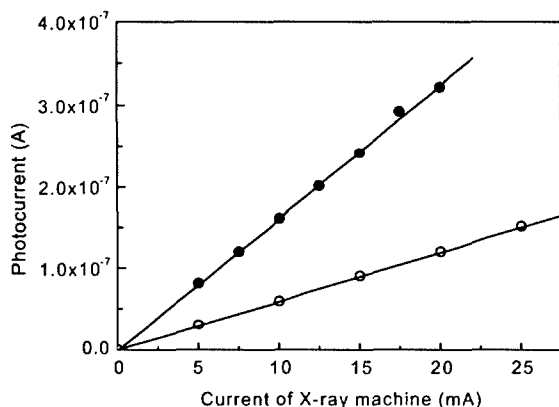
Figure 3. Current collected by the detector whose characteristics are given in figures 1 and 2 versus the current of the X-ray machine for accelerating voltage of 50 kV (●) and 30 kV (○).

Fig. 4 gives the signal dependence versus the applied reverse bias for two different value of I. As the bias, i.e. the space charge region, increases, the signal increases. For the lower value of I (10 mA) S follows the dependence expected if charge collection take place in space charge region. The fit with the calculated values is obtained assuming a charge collection efficiency of 28%. The calculation takes into account the energy distribution of the photons but makes abstraction of the photons of energy lower than 20 kV. Other data are obtained for I=20 mA with a similar charge collection efficiency (33%), but the theoretical dependence is not well reproduced at high biases. This is probably associated with signal saturation at high photon flux.
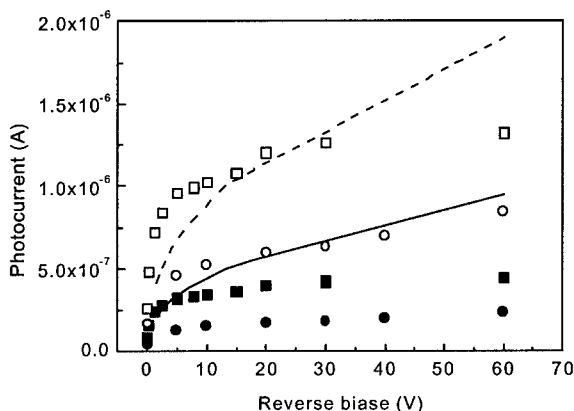
Figure 4. Current collected by the detector versus bias for currents of the X-ray machine of 10 mA (●) and 20 mA (■). The same data, but multipled by 3.5 (○) for 10 mA, and 3 (□) for 20 mA, are shown to compare with the calculated currents (solid and dashed lines, respectively) assuming a charge collection efficiency of 1.

CONCLUSION

The data we have presented illustrate that epitaxial GaAs, known to be a good candidate to make high resolution γ detectors at room temperature, could also be used to make high efficiency for detecting X-ray. The epitaxial layers we produce, with a simple, fast, cheap and non polluting technique, qualify for this. The active thickness of the detectors we have presented are limited by the level of residual doping and efforts are now made toward decreasing this level (5×10^{13} cm^{-3} has now been achieved).

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